



MODELING AND SIMULATION OF LIQUID MOLDING PROCESSES

Pavel Simacek
Center for Composite Materials
University of Delaware

UD-CCM • 1 July 2003

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 26 AUG 2004		2. REPORT TYPE N/A		3. DATES COVERED -	
4. TITLE AND SUBTITLE Modeling And Simulation Of Liquid Molding Processes				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University of Delaware Center for Composite Materials Newark, DE 19716				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution unlimited					
13. SUPPLEMENTARY NOTES See also ADM001700, Advanced Materials Intelligent Processing Center: Phase IV., The original document contains color images.					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UU	18. NUMBER OF PAGES 26	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

Outline



LIMS Simulation Package Development

- ♦ **Changes and Additions**
 - ♦ Inlet Modeling
- ♦ **LIMS UI Extensions and Development**
- ♦ **LIMS Distribution Made Available**

Addressing Practical Processing Issues

Modeling Issues

- ♦ **Preform and Distribution Media Deformation**

Conclusions

The Road Ahead

Outline



LIMS Simulation Package Development

- ♦ **Changes and Additions**
 - ♦ Inlet Modeling
- ♦ **LIMS UI Extensions and Development**
- ♦ **LIMS Distribution Made Available**

Addressing Practical Processing Issues

Modeling Issues

- ♦ Preform and Distribution Media Deformation

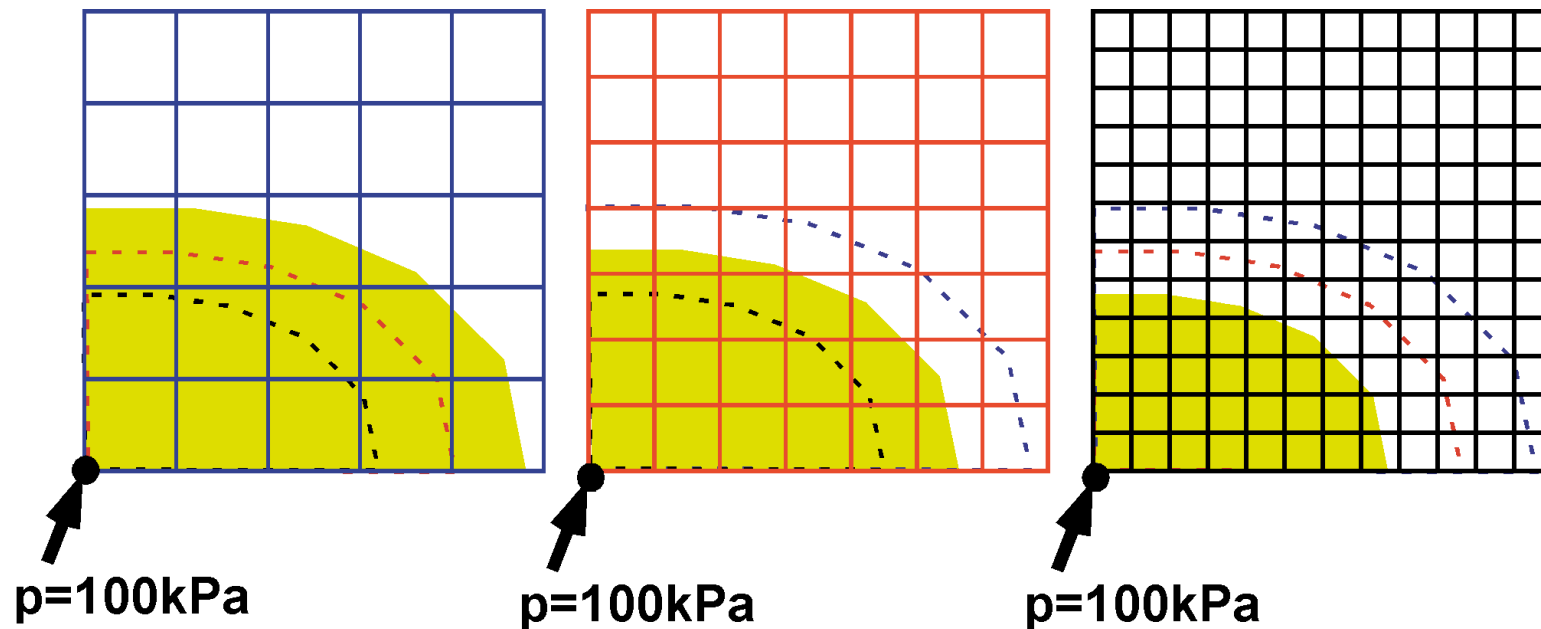
Conclusions

The Road Ahead

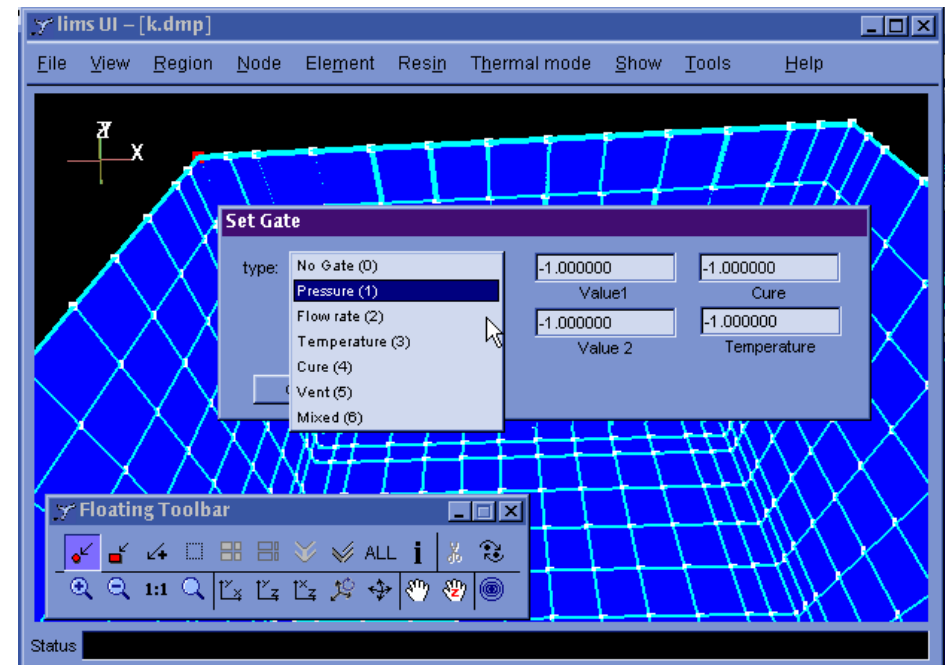
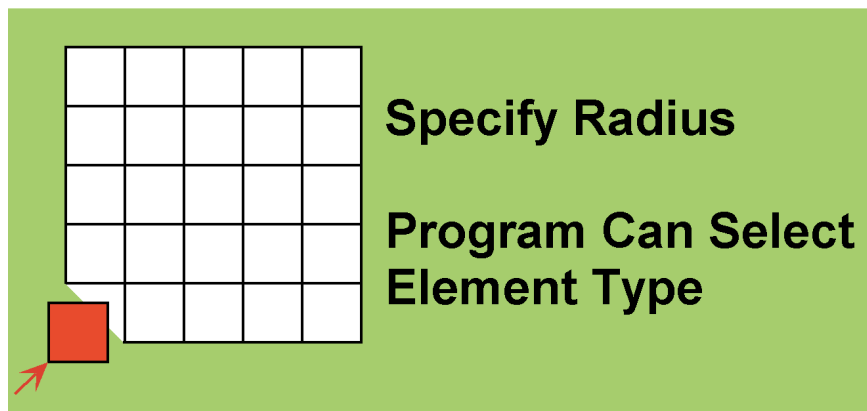
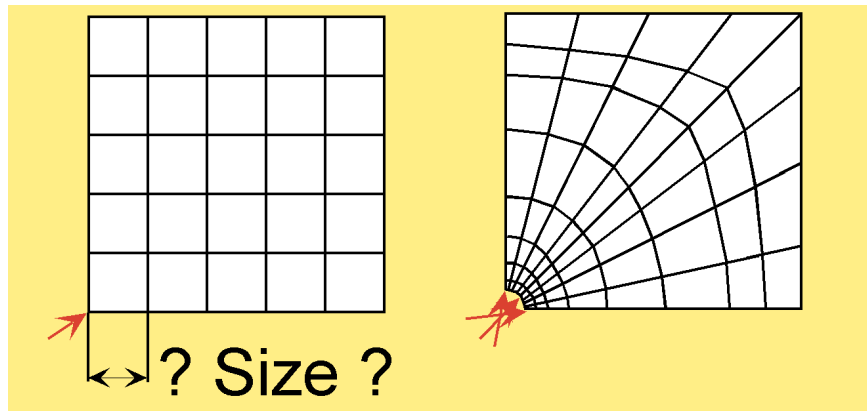
Element Size and Injection Gate



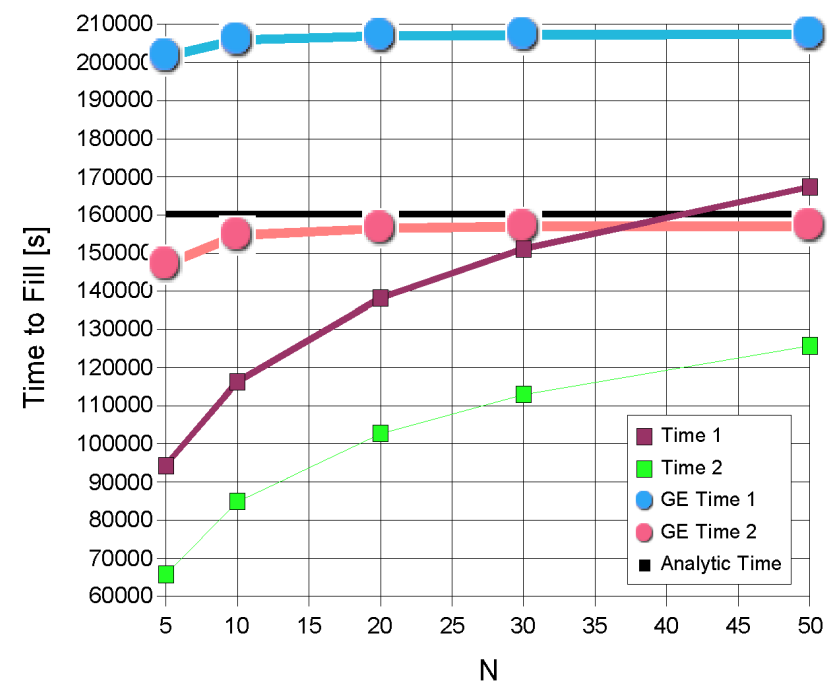
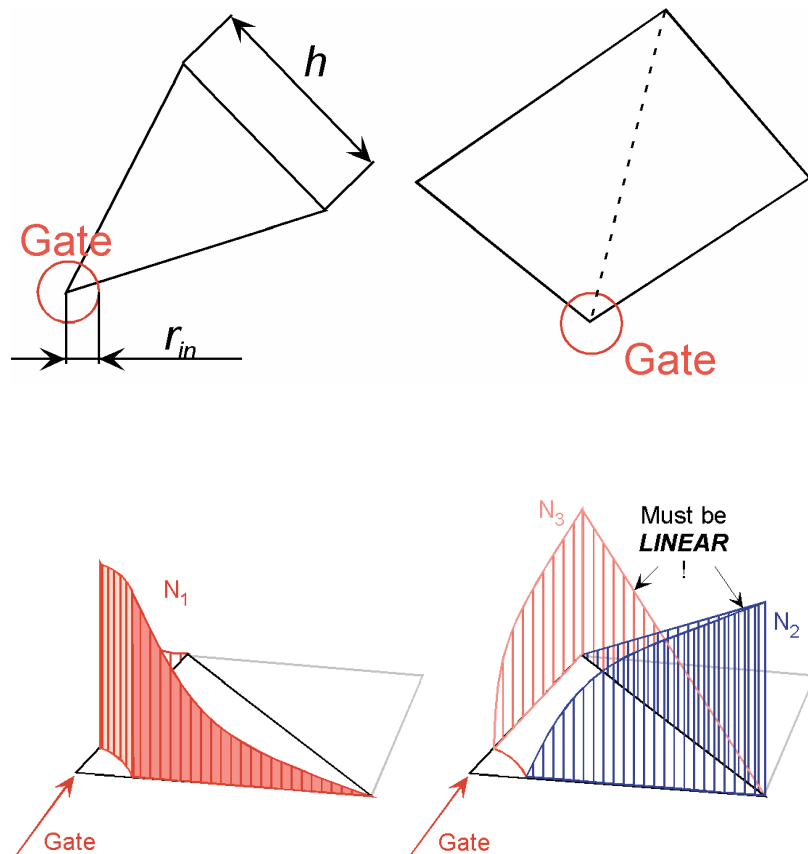
- ◆ Same Problem
- ◆ Same Time
- ◆ Refined Mesh
- ◆ Divergent Results at Given Time



“Proper” Gate Modeling and User Convenience



The “Gate Element” Implemented



LIMS UI: New Features



Injection Scheme Wizard

Toolsmenu

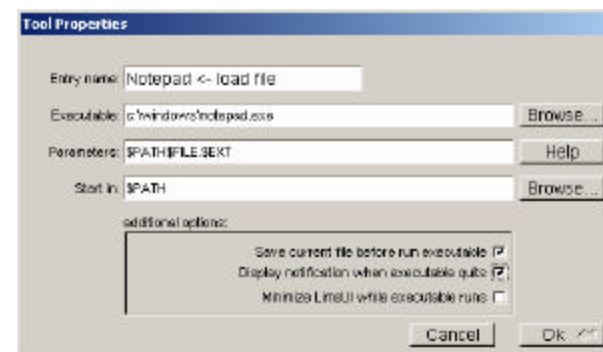
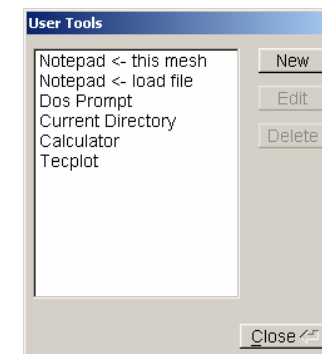
Floating Toolbar

Save (Without File Dialog)

Remove Result Section

Lots of Minor Additions and Fixes

- ♦ **Show commands passed to Lims while executing simulation**
- ♦ **Select all Gates**
- ♦ **Set Thermal Data**
- ♦ **Display Mode: 3D Elements**
- ♦ **Fullscreen Mode**
- ♦ **Select All Gates**
- ♦ ...



LIMSUI Development: Wizards



lms UI - [k.dmp]

File View Region Node Element Resin Thermal mode Show Tools Help

Standard

Injection Scheme Wizard

Step 1: Set initial gates.

Entry#	Node#	Type
00001	0000000127	initial gate

add gates/vents:

127
Node# for Gate/Vent: 02
DAQ
Pressure (1)
Type
100000
Value

Node# for Open: 01
DAQ

Injection Scheme Wizard

Step 2: Set auxiliary gates.

Entry#	Node#	Type
00001	0000000127	initial gate

add gates/vents:

139
Node# for Gate/Vent: 02
DAQ
Pressure (1)
Type
100000
Value

140
Node# for Open: 01
DAQ

Injection Scheme Wizard

Step 3: Set vents.

Entry#	Node#	Type	Open#
00001	0000000127	initial gate	

add gates/vents:

139
Node# for Gate/Vent: 01
DAQ
Pressure (1)
Type
100000
Value

140
Node# for Open: 01
DAQ

use

Cancel

telephony.bd test.lb

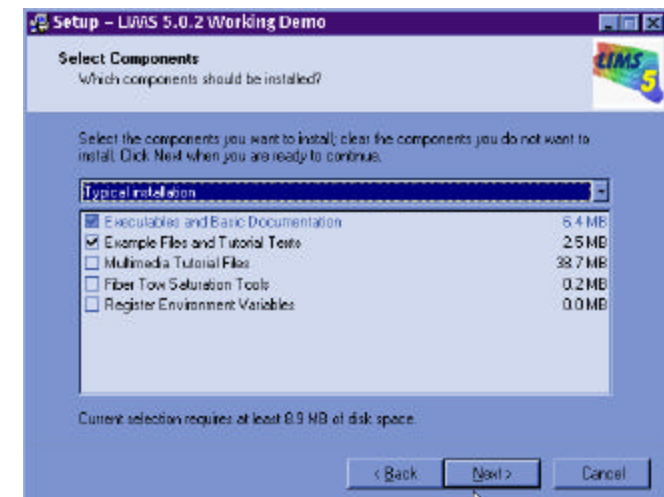
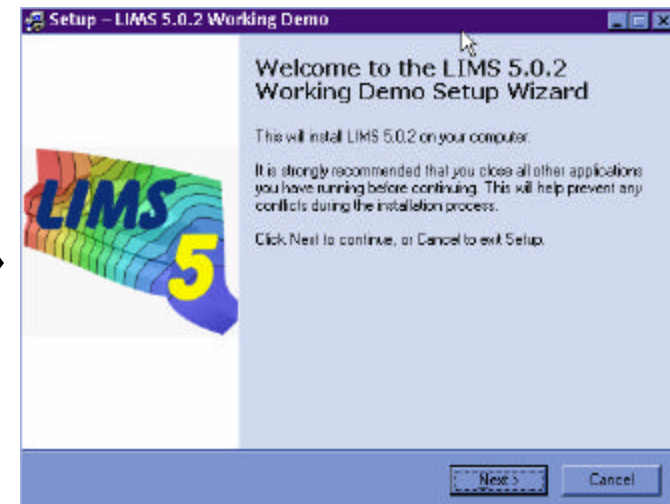
```

1 proc auto
2
3 READ "k.dmp"
4
5 setgate 127, 1, 100000
6
7 do while (sonumberempty()>0)
8 solve
9
10 if (sofillfactor(27)>0) then
11 setgate 127, 0, 0
12 endif
13
14 loop
15
16 SETOUTTYPE "TPLT"
17 WRITE "k.tec"
18
19 endproc
    
```

Status

1:1 / 19 [226] p 112 \$70 LBASIC

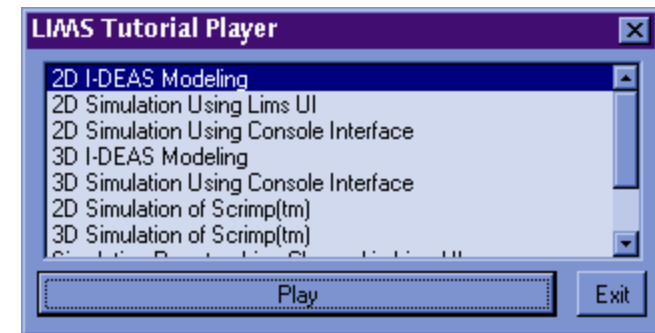
LIMS Distribution: Install CD



LIMS Distribution: Details



- **“Standard” LIMS Distribution Was Created**
 - **Setup Program**
 - **Uninstall**
- **Multimedia Tutorial Created**
 - **Supplements “Printed” Documentation**
- **“Limited” Version Distributed Without Limitations**
 - **1000 Nodes, Times Out**
- **Full Version Subject to Agreement**



LIMS Distribution: Technology Transfer



LIMS Demonstration CD

- ♦ Companies (Lockheed Martin, Raytheon Missile System, ACR, Dynasty Boats...)
- ♦ Universities

Workshops and Demonstrations

- ♦ SAMPE, JEC ...
- ♦ Workshops (ACR, 2nd July...)

Outline



LIMS Simulation Package Development

- ◆ Changes and Additions
 - ◆ Inlet Modeling
- ◆ LIMS UI Extensions and Development
- ◆ LIMS Distribution Made Available

Addressing Practical Processing Issues

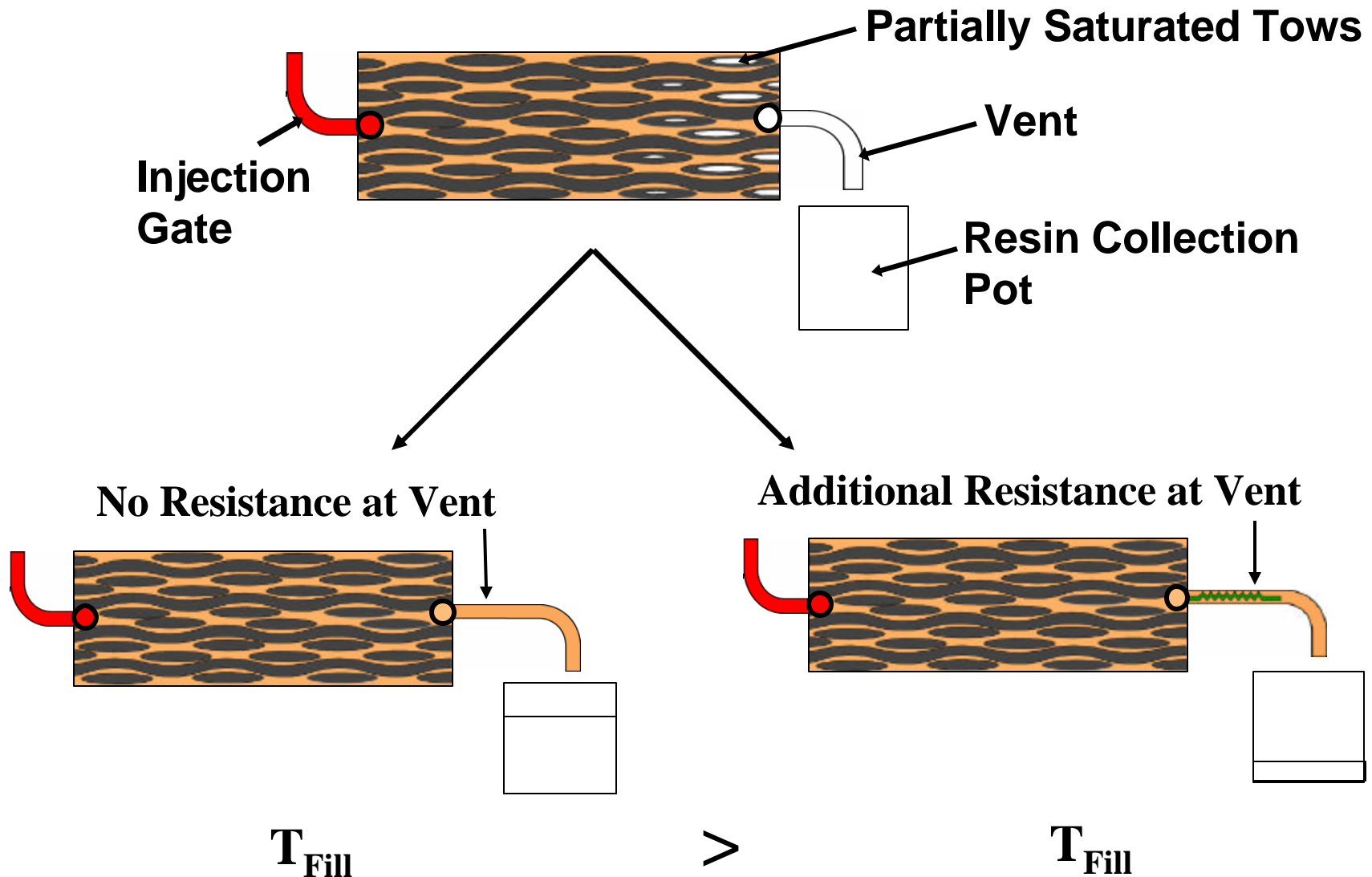
Modeling Issues

- ◆ Preform and Distribution Media Deformation

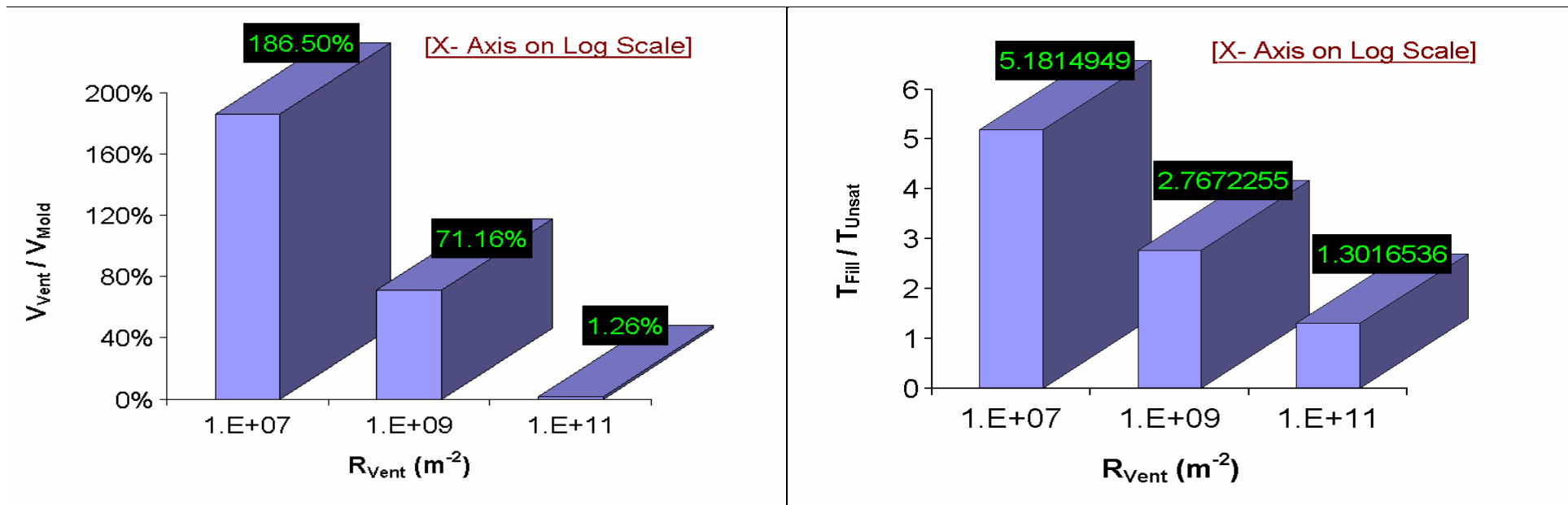
Conclusions

The Road Ahead

Modeling Flow Resistance at Vent



Effects of Flow Resistance at Vent



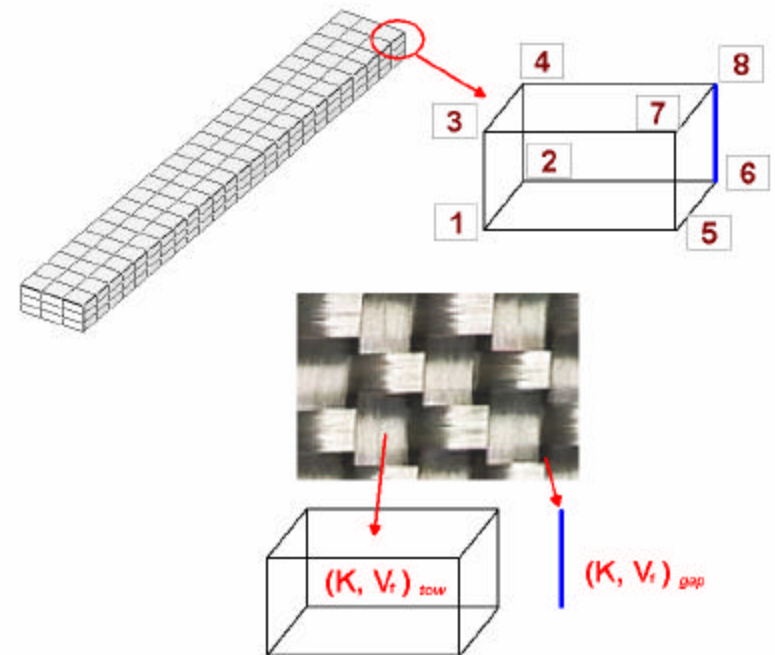
R_{Vent} - Resistance at the Vent

V_{Vent} - Volume of Resin Leaking out of the Vent for Full Saturation

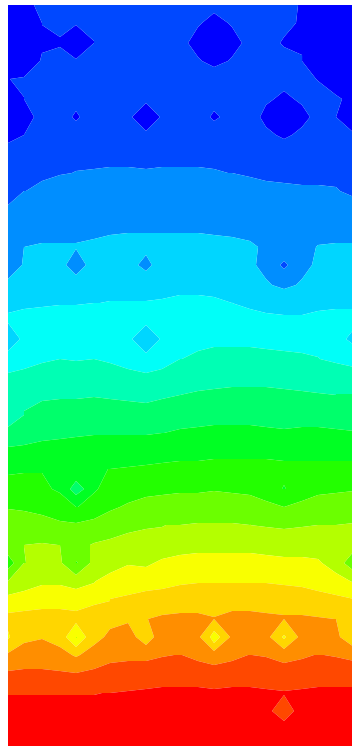
V_{Mold} - Porous Volume of Mold

T_{Fill} - Fill-Time for Full Saturation of Mold

T_{Unsat} - Time When Resin First Reaches at the Vent



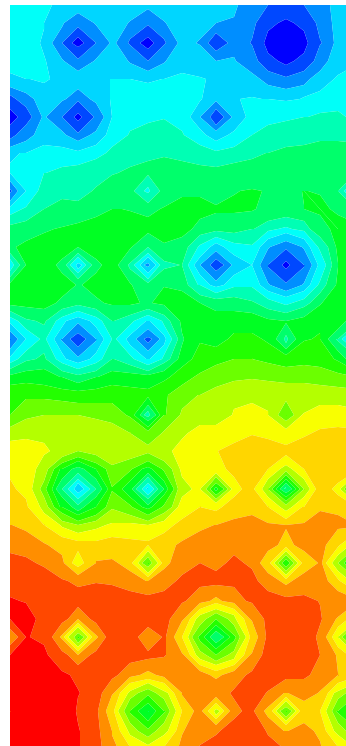
Influence of Distribution Layer Permeability



$$K_{dl} = 10^{-3} \text{ mm}^2$$

Time

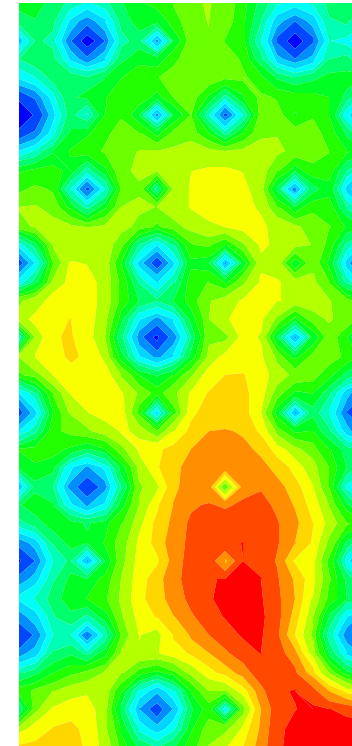
237.882
222.023
206.165
190.306
174.447
158.588
142.729
126.87
111.012
95.1529
79.2941
63.4352
47.5764
31.7176
15.8588



$$K_{dl} = 10^{-2} \text{ mm}^2$$

Time

44.4522
41.4887
38.5253
35.5618
32.5983
29.6348
26.6713
23.7078
20.7444
17.7809
14.8174
11.8539
8.89044
5.92696
2.96348

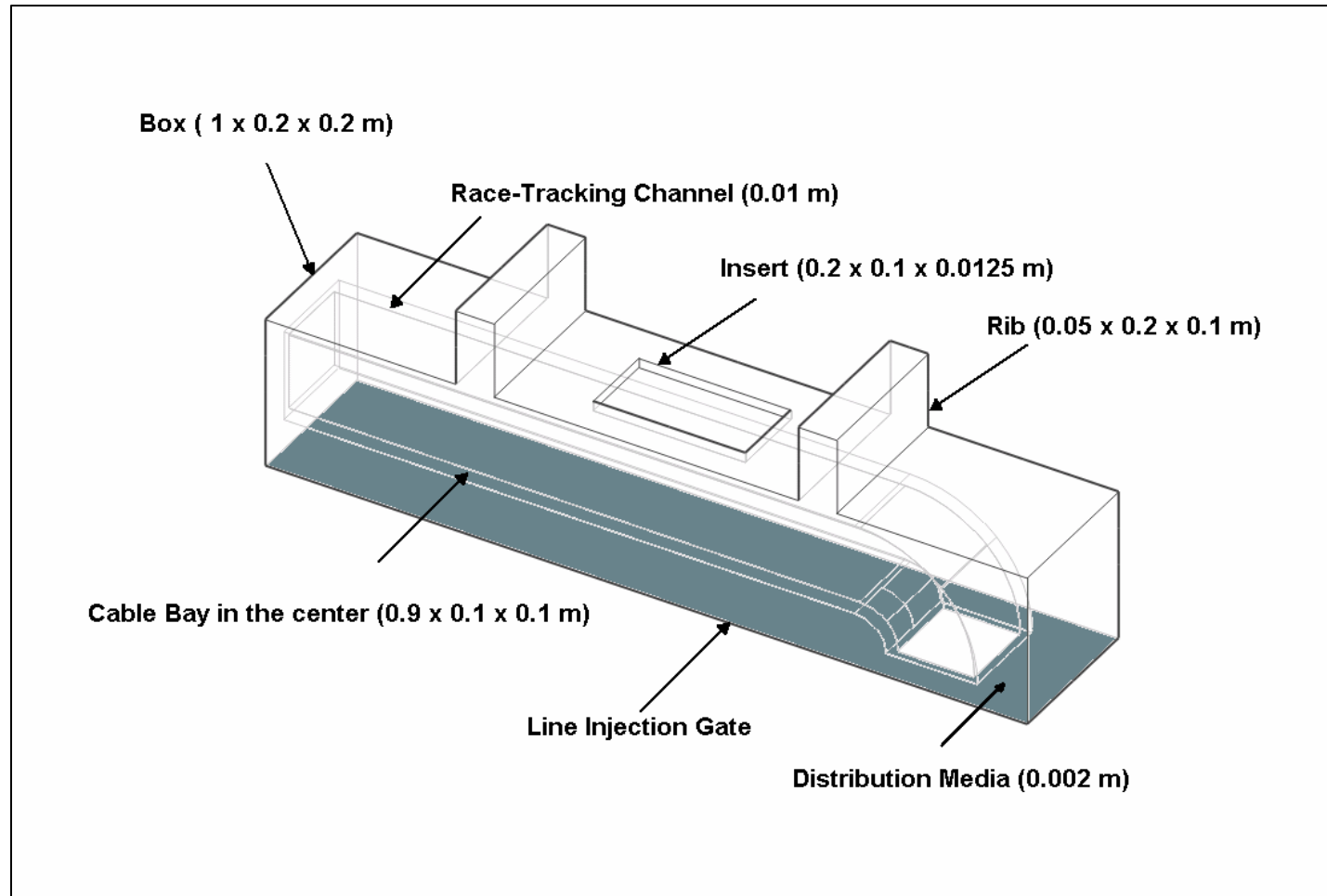


$$K_{dl} = 10^{-1} \text{ mm}^2$$

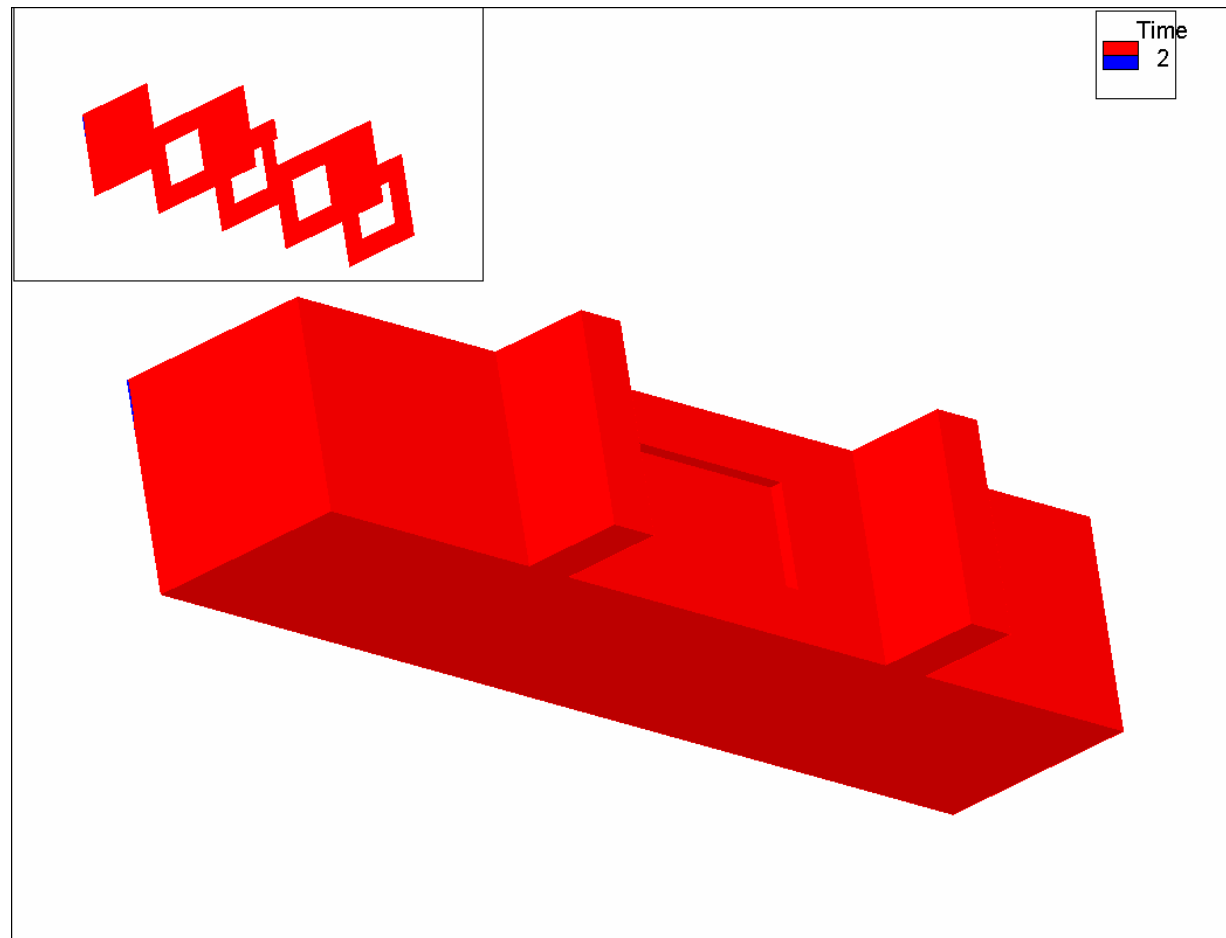
Time

16.1802
15.1015
14.0229
12.9442
11.8655
10.7868
9.70813
8.62945
7.55077
6.47209
5.39341
4.31472
3.23604
2.15736
1.07868

Modeling Inserts and Channels Inside the Part



Integrated Part: Filling



Outline



LIMS Simulation Package Development

- ♦ Changes and Additions
 - ♦ Inlet Modeling
- ♦ LIMS UI Extensions and Development
- ♦ LIMS Distribution Made Available

Addressing Practical Processing Issues

Modeling Issues

- ♦ **Preform and Distribution Media Deformation**

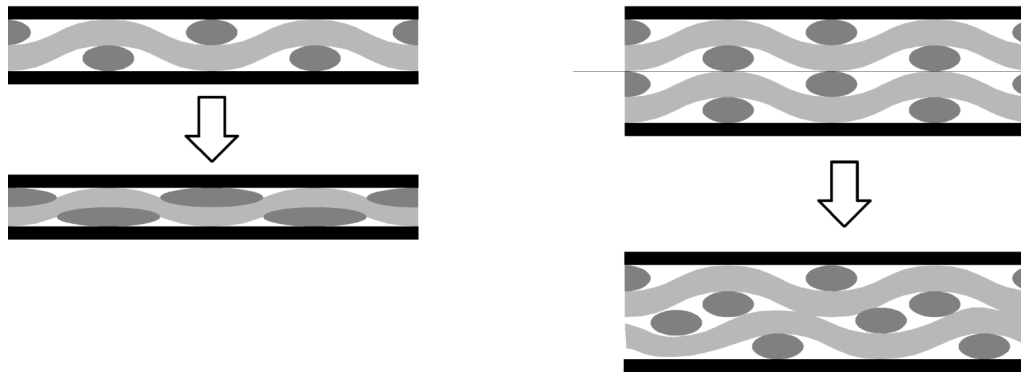
Conclusions

The Road Ahead

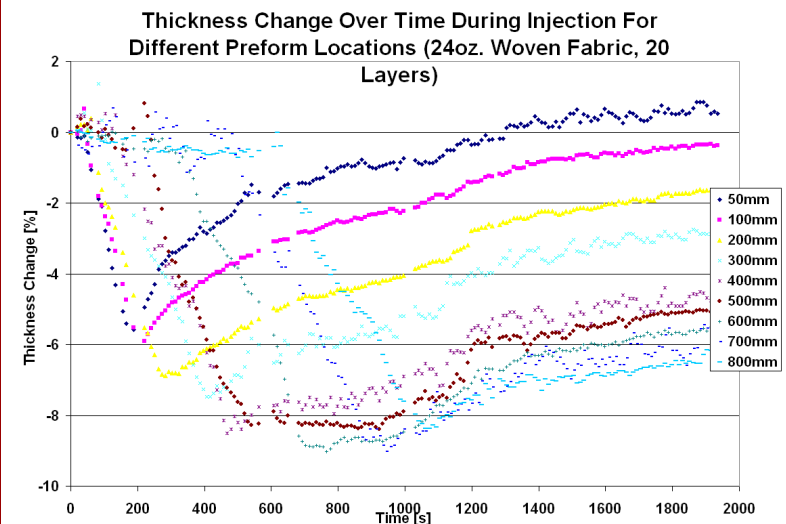
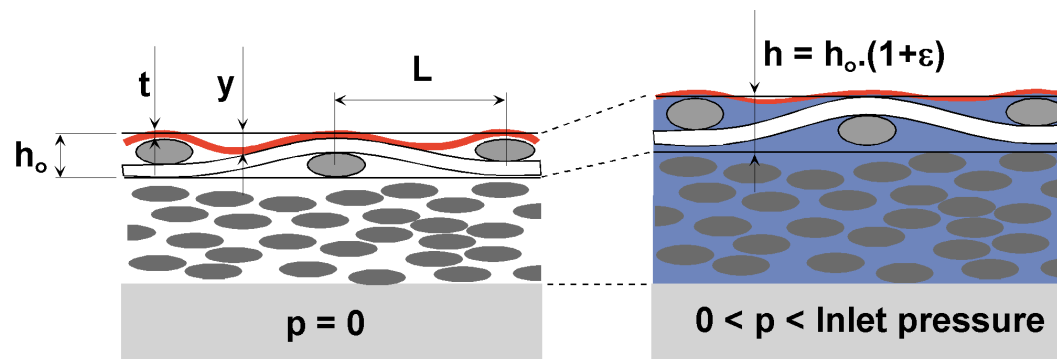
Preform & Distribution Media Deformation



RTM



VARTM

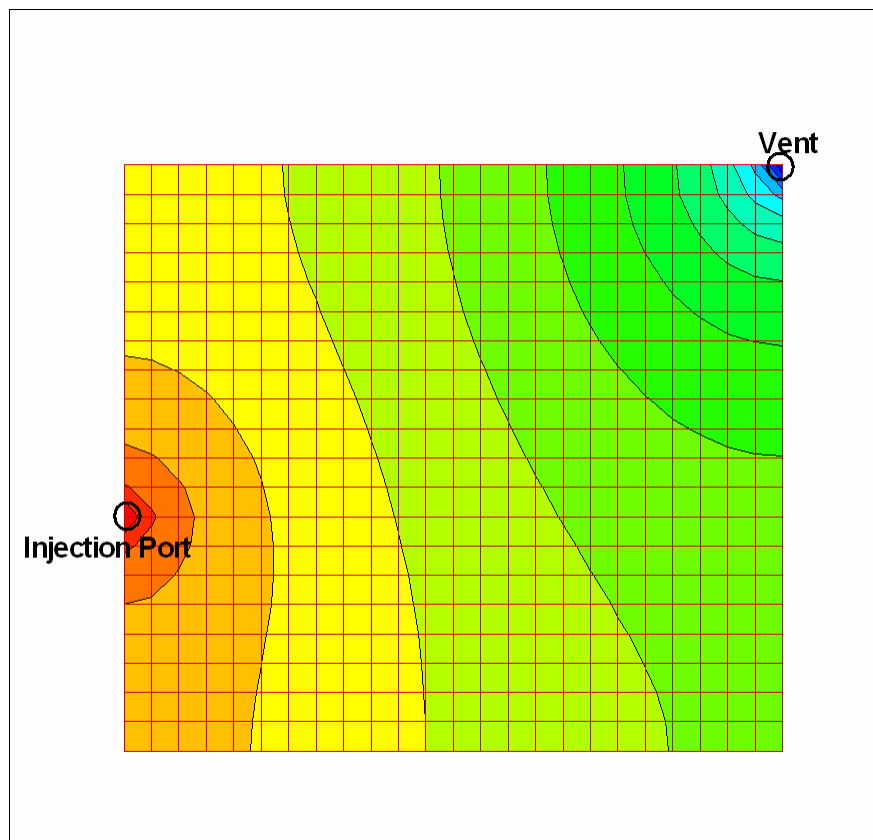


Compaction: Is It Important?

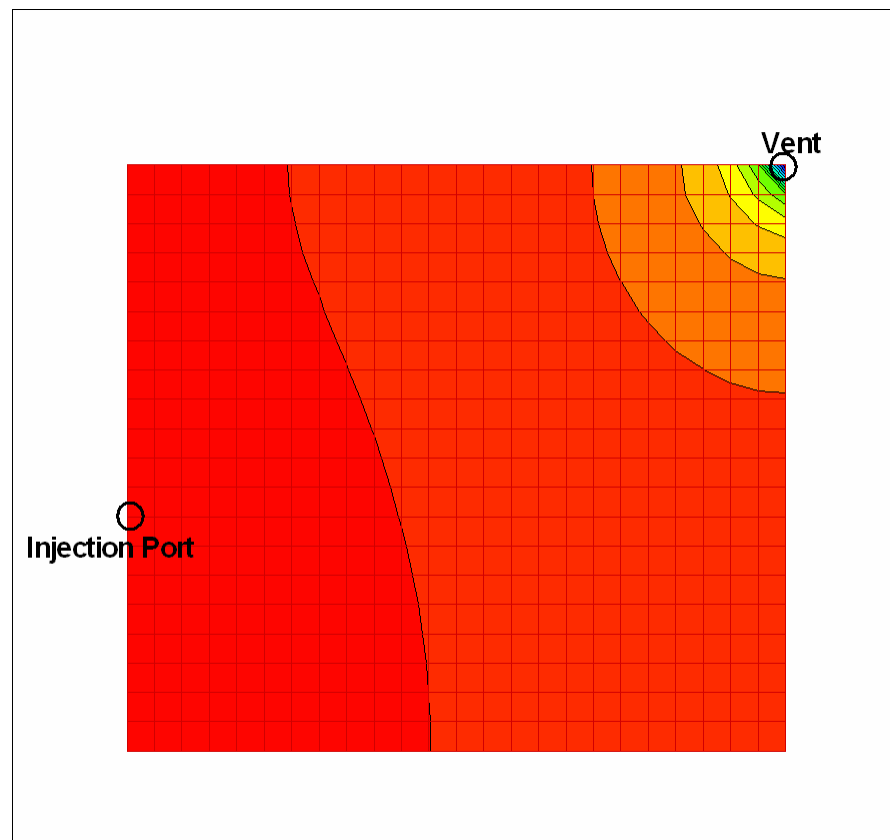


Pressure Field in Rectangular Mold (End of Injection)

No Compaction



Compaction

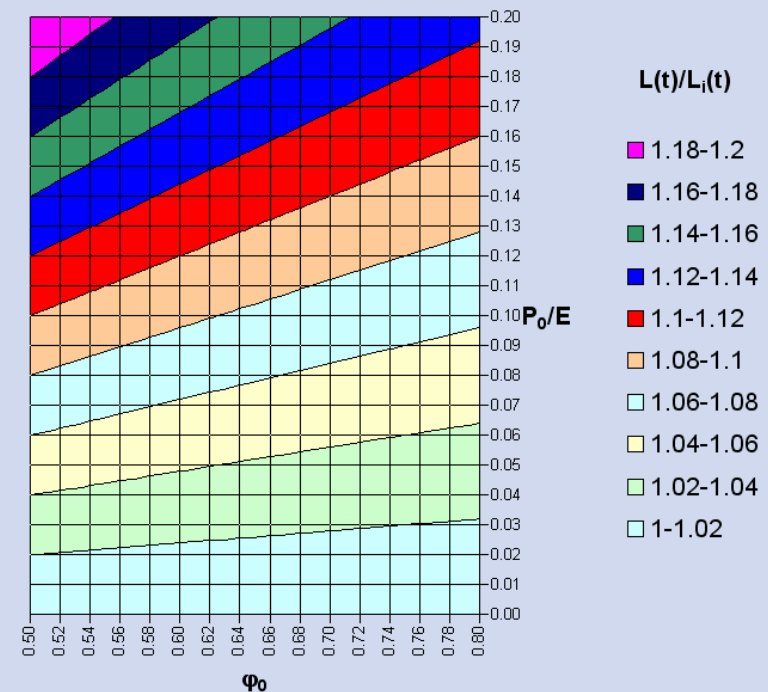


Compaction: The Analytic Solution



$$L(t) = \sqrt{\frac{10kE}{16\mu(1-\varphi_0)^2}} \frac{\left(\varphi_0 + \frac{P_0}{E}\right)^4 - (\varphi_0)^4}{\sqrt{\left(\varphi_0 + \frac{P_0}{E}\right)^5 - (\varphi_0)^5}} \sqrt{t}$$

$$\frac{L(t)}{L_i(t)} = \frac{\sqrt{5}}{4\varphi_0} \sqrt{\frac{E}{P_0}} \frac{\left(\varphi_0 + \frac{P_0}{E}\right)^4 - (\varphi_0)^4}{\sqrt{\left(\varphi_0 + \frac{P_0}{E}\right)^5 - (\varphi_0)^5}}$$



Outline



LIMS Simulation Package Development

- ◆ Changes and Additions
 - ◆ Inlet Modeling
- ◆ LIMS UI Extensions and Development
- ◆ LIMS Distribution Made Available

Addressing Practical Processing Issues

Modeling Issues

- ◆ Preform and Distribution Media Deformation

Conclusions

The Road Ahead

Conclusions



- **Gate Elements Were Implemented and Tested**
- **Preform and Distribution Media Compaction**
 - ◆ **Influences Behavior of VARTM Process and Other**
 - ◆ **Analytic Model Was Developed**
- **LIMS UI Has Been Extended with Sequential Injection Wizard and Improved**
- **LIMS Distribution Was Completed and Made Available**

The Road Ahead



Simulation Tasks

- ♦ Numerical Solution for Deformable Media
- ♦ Re-visiting the Non-isothermal Modeling

LIMS Extension

- ♦ Extending Gate Elements into 3D Case
- ♦ Alternative (Iterative) Solver for Large/Non-Linear Problems

LIMS UI

- ♦ Connection to Databases of Material Properties
- ♦ Wizard for Optimal Filling

Credits



Students

Dhiren Modi

LIMS UI Team

Ben Lenhard

Mark Schlieker

**This work was sponsored by ONR under
Contract No. N00014-02-1-0811**